Producibility Aspects of Composite Material Qualification and Certification

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AEROMAT

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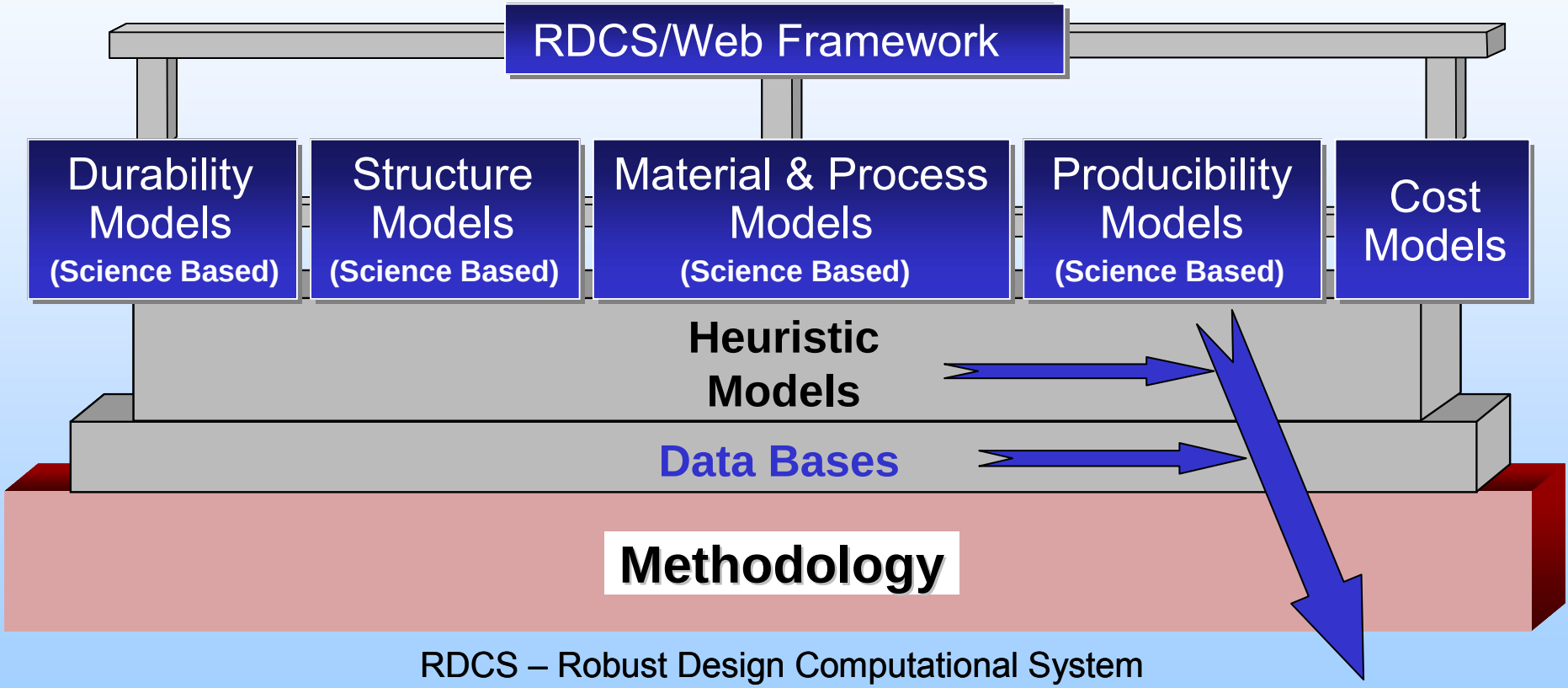
This program was developed under the guidance of Dr. Steve Wax and Dr. Leo Christodoulou of DARPA. It is under the technical direction of Dr. Ray Meilunas of NAVAIR.

Overall Program Concept

The Objective of the AIM-C Program is to Provide Concepts, an Approach, and Tools That Can Accelerate the Insertion of Composite Materials Into DoD Products



RDCS – Robust Design Computational System

Module: linked set of related models/databases; 8 in AIM-C Phase I Program - Resin, Fiber, Prepreg, Processing, Lamina, Structures, Durability, and **Producibility**

Producibility Module Definitions

Definition:

A Controller Module to Compare Requirements to Manufacturing Capabilities For Quality Components

Corollaries:

- ***Can I Make It?***
- ***With What Degree of Success?***
- ***How Can I Make It?***
- ***By Which Manufacturing Sequence Should It Be Made?***

- **The Initial Envisioned Module Provides Heuristics Which Give Guidance Through Part Thermal Processing (Cure/Post Cure)**
- **Higher Level Module That Manages And Guides The Other Modules To Exercise Only The Tools That Are Necessary To Address The Designers Requirements**
- **Phase 1 Program Only Looking At Autoclave Processing**

Producibility Module Definitions

Additional Definitions:

- **Manufacturing Capabilities**
  - Ability to Fabricate the Unassembled Components with Identified Materials and Manufacturing Methods

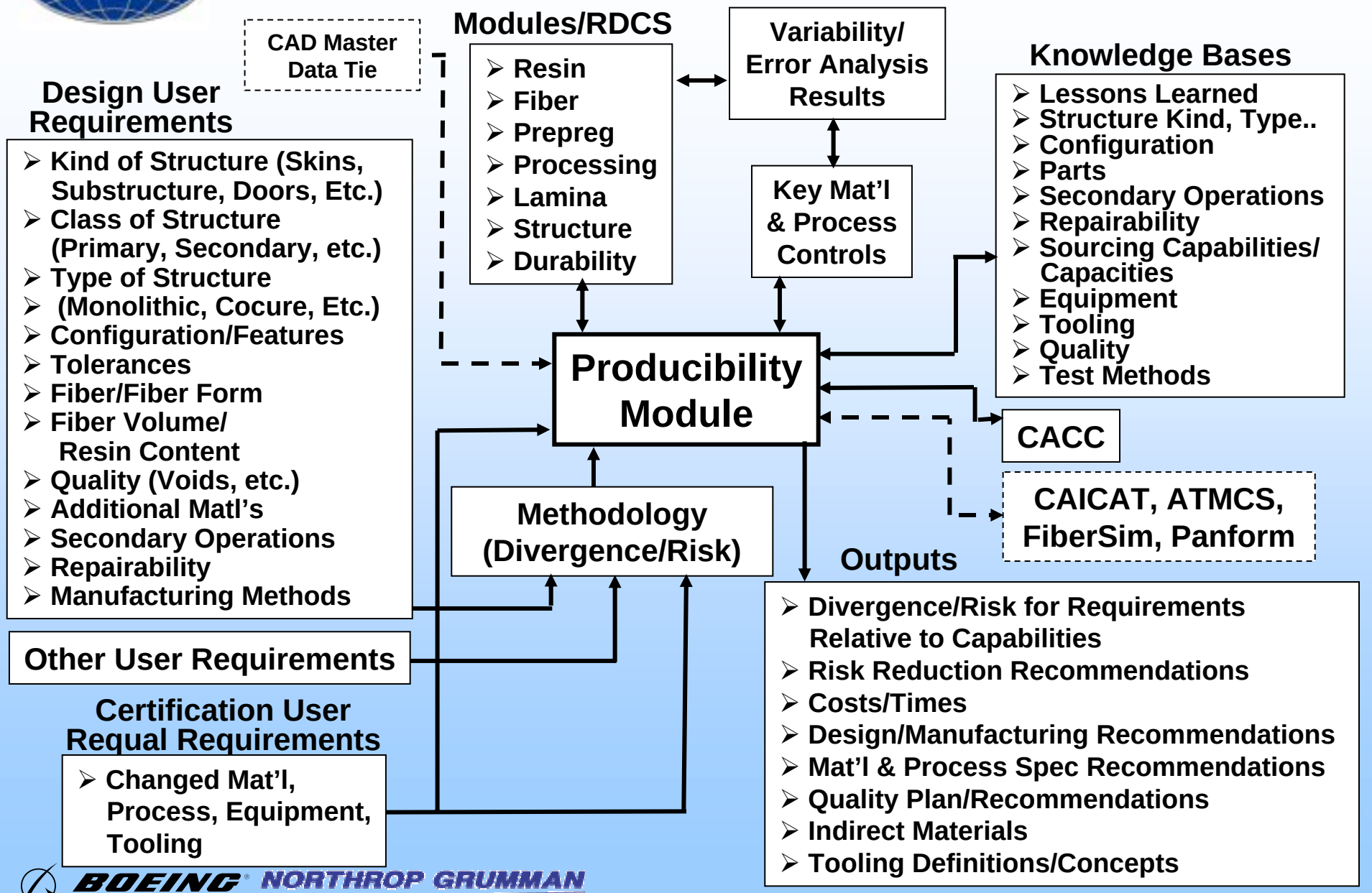
- **Manufacturing/Processing Steps/Areas**
  - Ply Cutting
  - Layup
  - Debulking
  - Bagging
  - Equipment
  - Tooling
  - Repairability

- **Quality Requirements/ Parameters**
  - Meets Functional Requirements (Strength, Stiffness, Dimensions, Etc.)
  - Requirements/Parameters are Identifiable, Measurable, and Boundable

- **Component Quality Requirements/Parameters**
  - Dimensions
  - Voids
  - Porosity
  - Inclusions
  - Surface Waviness
  - Fiber Volume/Resin Content
  - In-Plane & Out of Plane Fiber Distortion
  - Surface Finish

- **In-Process Quality Requirements/Parameters**
  - Ply Angle
  - Ply Lap/Gap
  - Out Time
  - Freezer Time
  - Equipment Certifications
  - Heat-up Rates
  - Cure Time, Temp, Pressure
  - Abort Conditions
  - Debulk Time, Temp, Pressure

Module Functional Flow Chart



Producibility Module Software

Most aspects of producibility are very subjective and/or based on previous experience with very little existing software. Therefore, it is proposed to use existing software capable of logical programming along with data bases that will contain pertinent information to be interrogated through SQL.

- **Heuristic and/or Rule Based Software (Java, Visual Basic, C++….)**
- **Knowledge/Data Bases (Access, Oracle, M-Vision,…)**
- **Science Based Objective Models (Fortran, C++, etc.)**
  - **CACC** (Thickness, Voids/Porosity, Resin Flow Bagging, Debulking, Tooling, etc.)

Red = Basic Activity

Knowledge/Data Bases

Manufacturing/Processing Steps
- Cutting
- Layup
- Debulking
- Cure
- NDE/Quality
- Testing

Equipment
- Cutting
- Collation
- Ovens
- Autoclaves
- NDE
- Testing

Lessons Learned
- Configuration/Type/ Class (Parts)
- Methodology
- Material(s) and Material Combinations
- Manufacturing/ Processing Steps
- Tooling
- Equipment
- Quality (In-process and Final Part)
- Testing/Evaluations
- Secondary Operations
- Repair
- RDT&E Costs/Times?

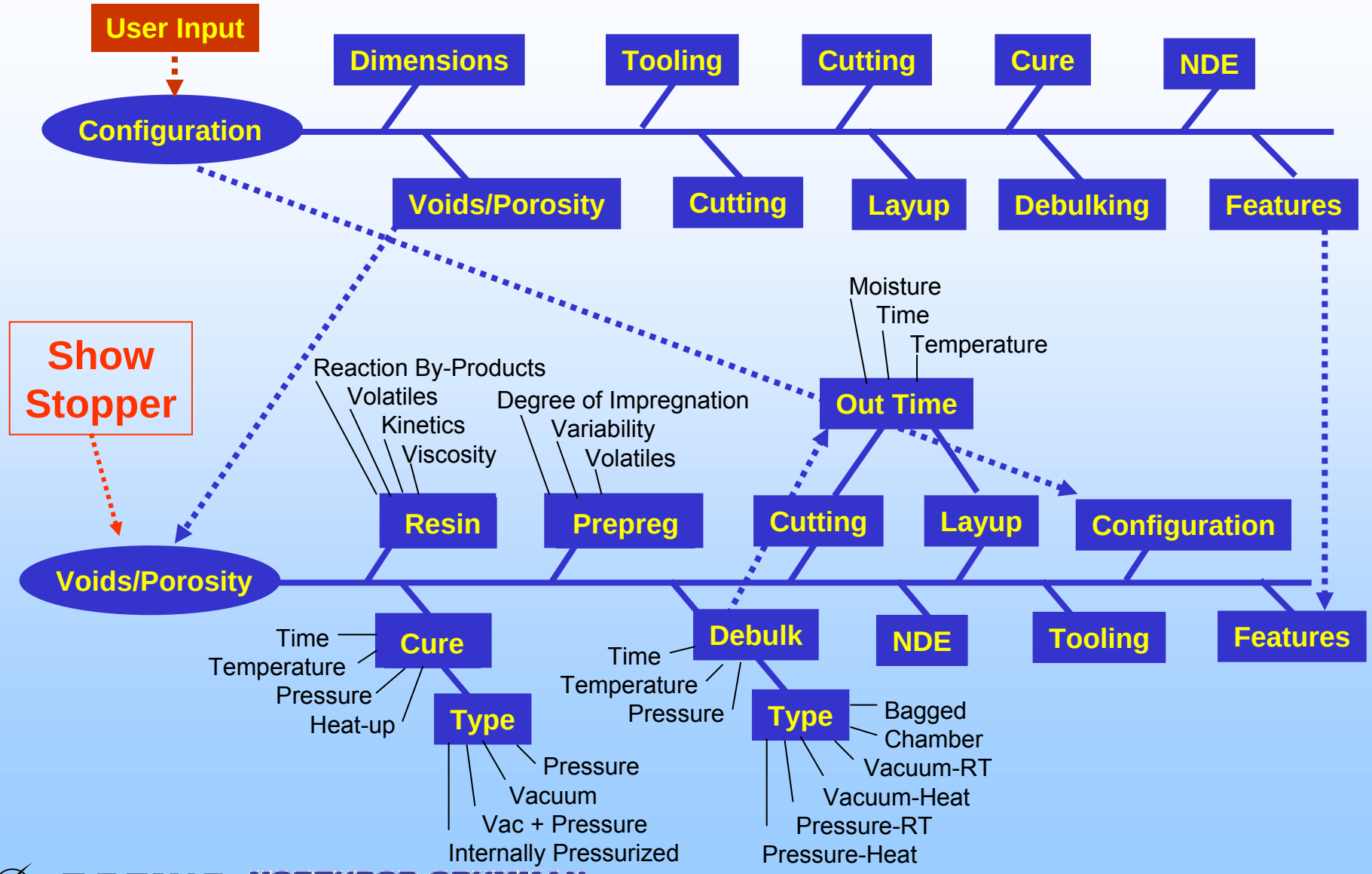
Tooling
- Primary Tooling
- Secondary Tooling

Secondary Operations
- Bonding
- Painting
- Coating

Repair
- In-process
- Final Part (After Cure)
- Material Compatibility

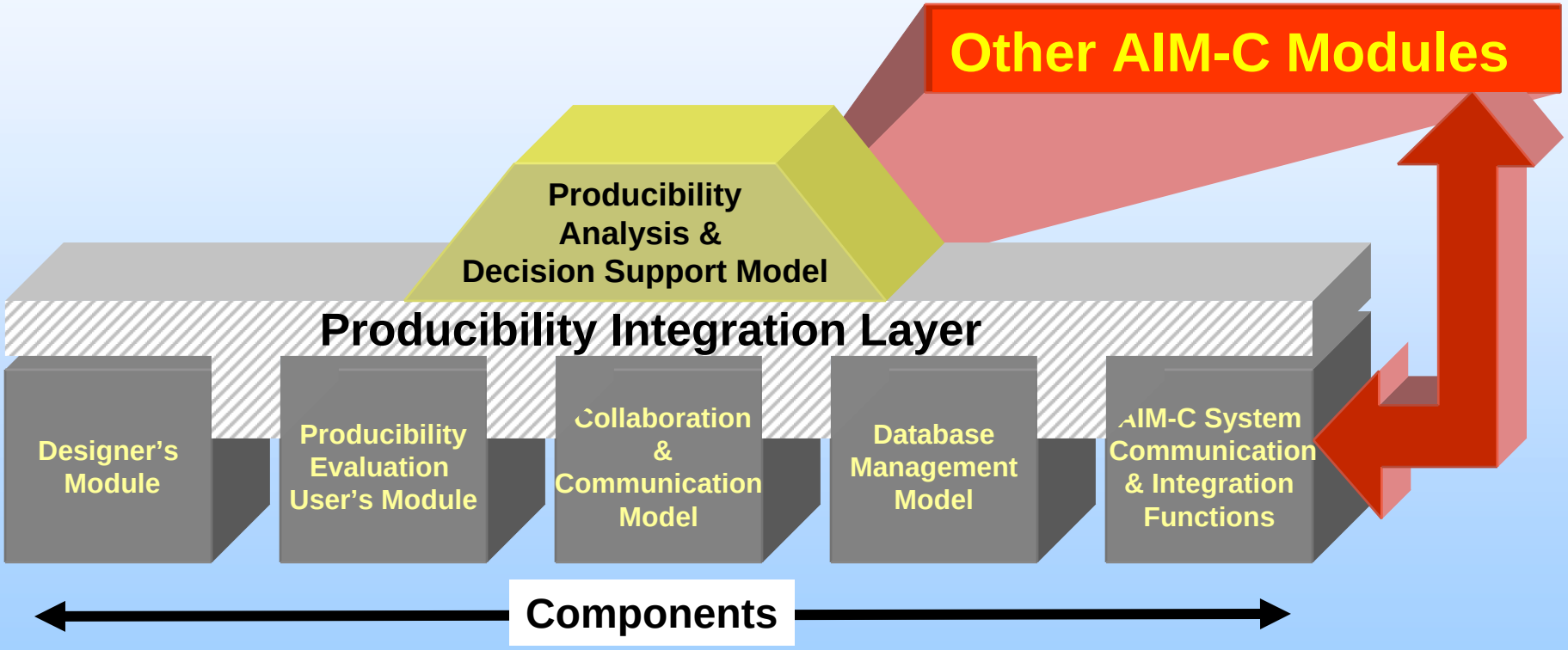
Other
- Health & Safety
- ITAR
- Proprietary Info

Cause and Effect Diagrams



AIM-C Producibility Module

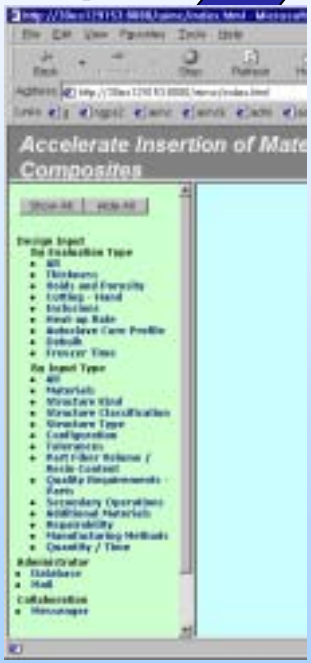
Producibility Module Has Integrated Components That In Turn…….



…..Are Integrated With Other AIM-C Modules

Producibility Module Demo Overview

Design User Inputs



- Primary Matl's
- Size/Thickness
- Features
- Tolerances
- Quality Requirements

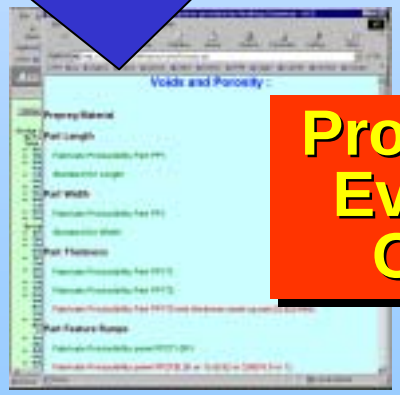
Producibility Item(s) Evaluation

- Thickness
- Voids/Porosity
- Cutting
- Indirect Matl's

Knowledge/Data Bases

Referenced/ Required Information

- Lessons Learned
- Indirect Materials
- Testing/ Specs



Producibility Evaluation Outputs

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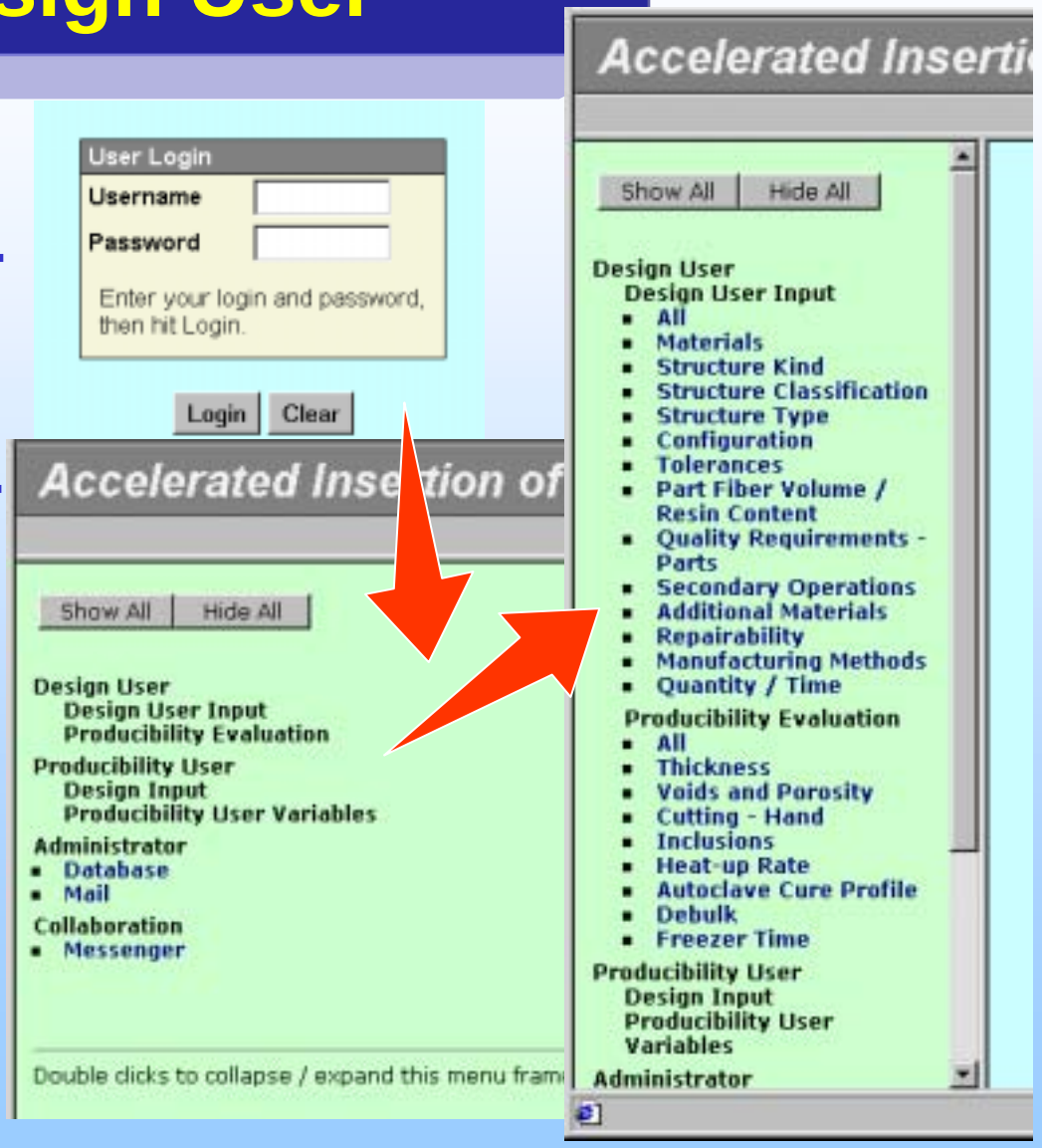
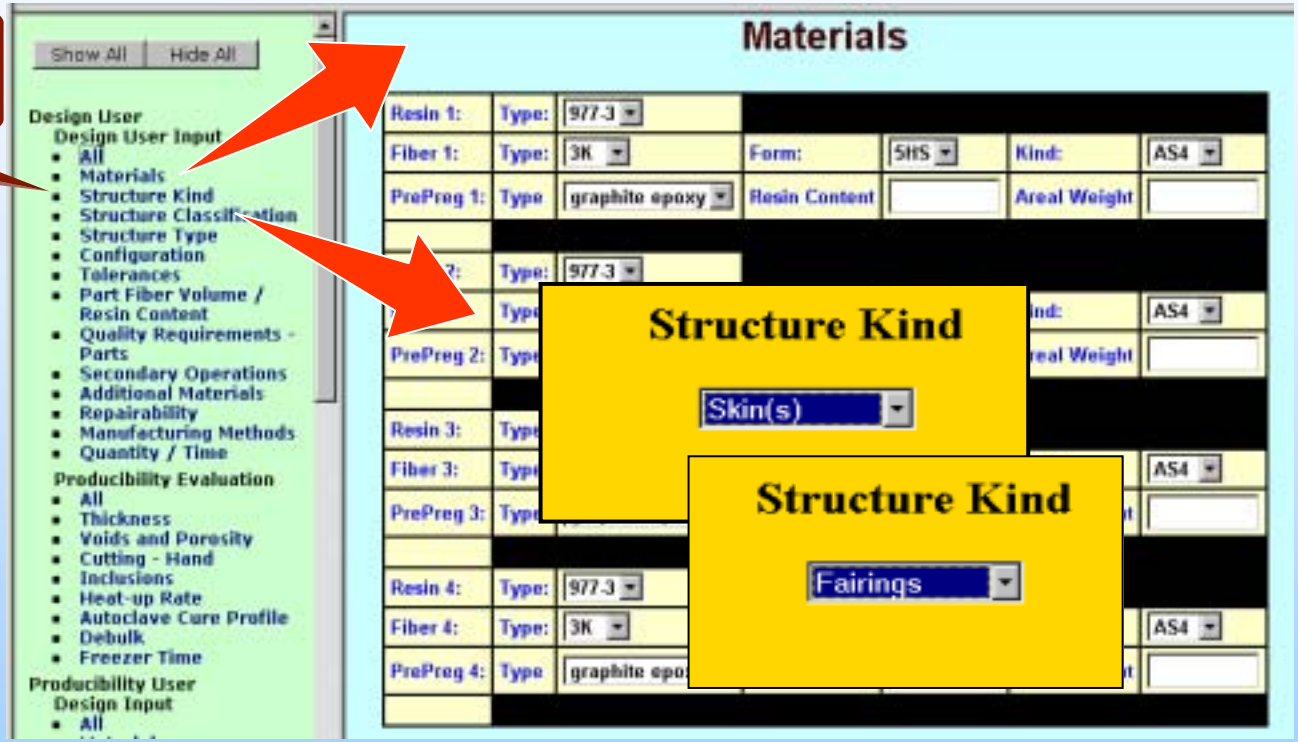
Starting Module Design User

- Control of Users
- Multiple User Types
- Administration Control for Data Bases
- Design User Variables for Producibility
- Producibility Evaluations From a Design User Standpoint
- Producibility Evaluations From a Producibility User Standpoint



Design User Inputs

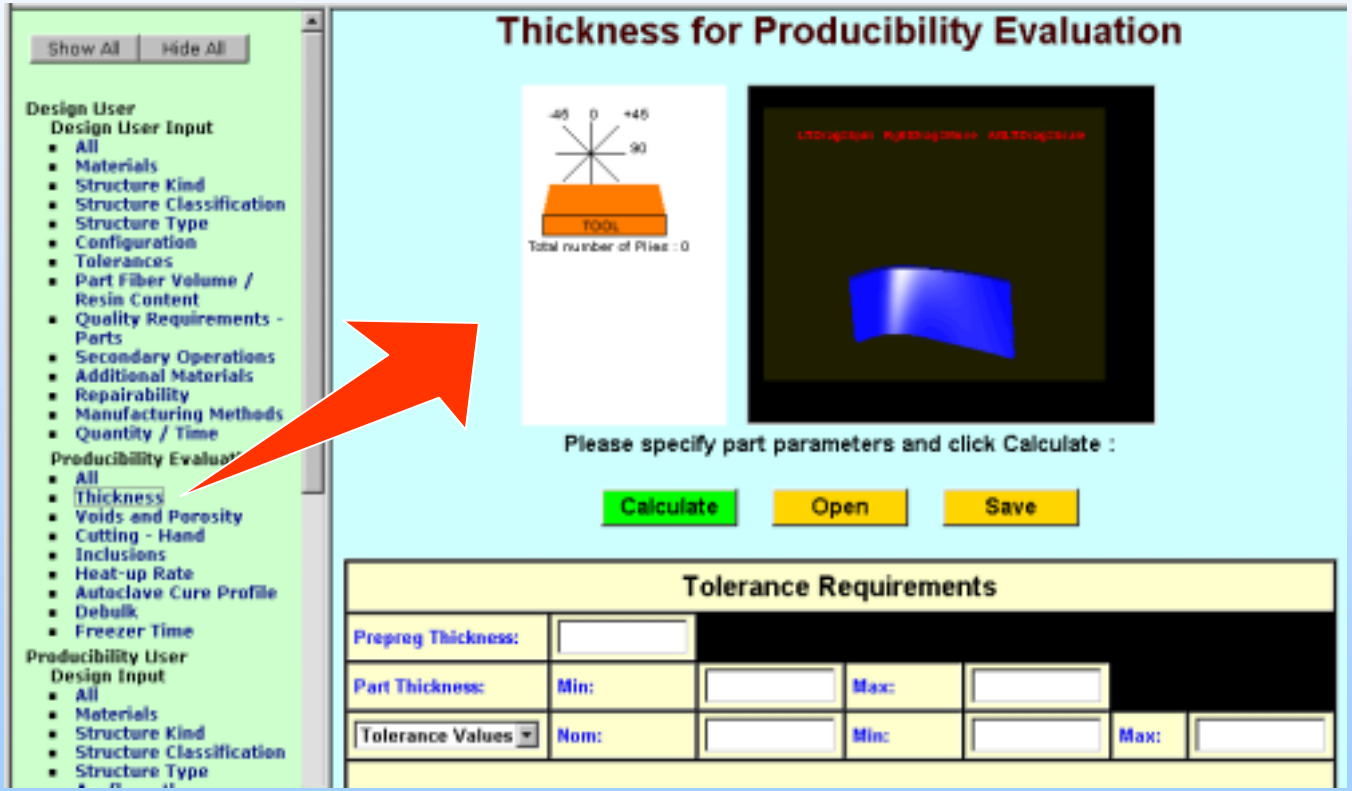
Design User Definable Variables



- Design User Sets Problem/Requirements For Producibility Evaluations
- Ties to Other Design User Items
- Allows Individual Producibility Item Evaluations or All Items

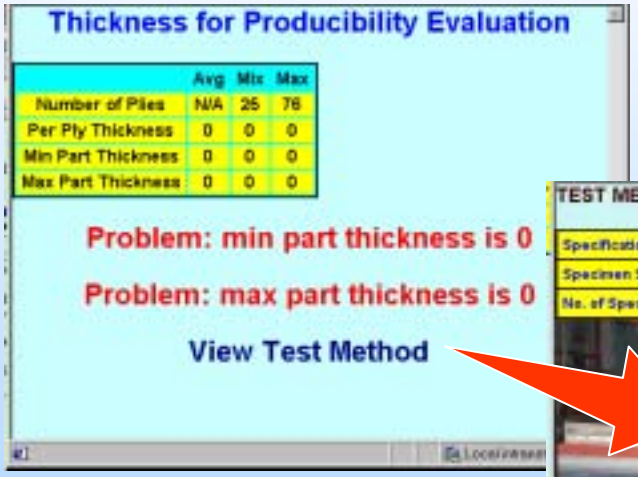
Producibility Evaluations/Outputs According to User Inputs/Requirements

Producibility – Quality Thickness



Ties to Resin, Fiber, and Prepreg Modules

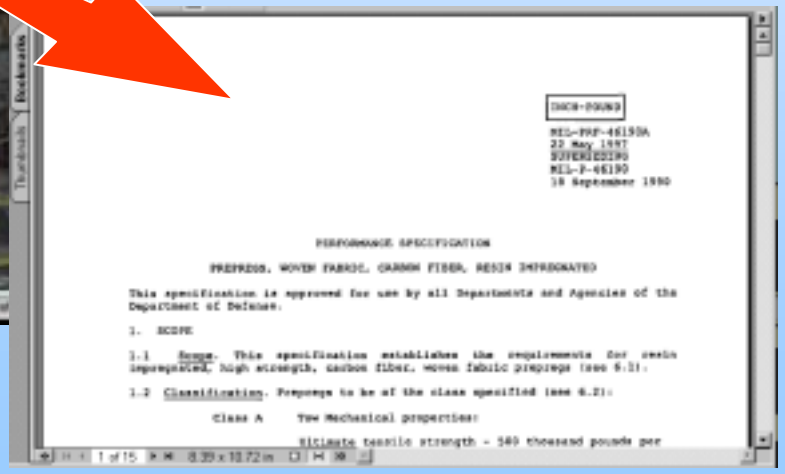
Producibility – Quality: Thickness



Testing

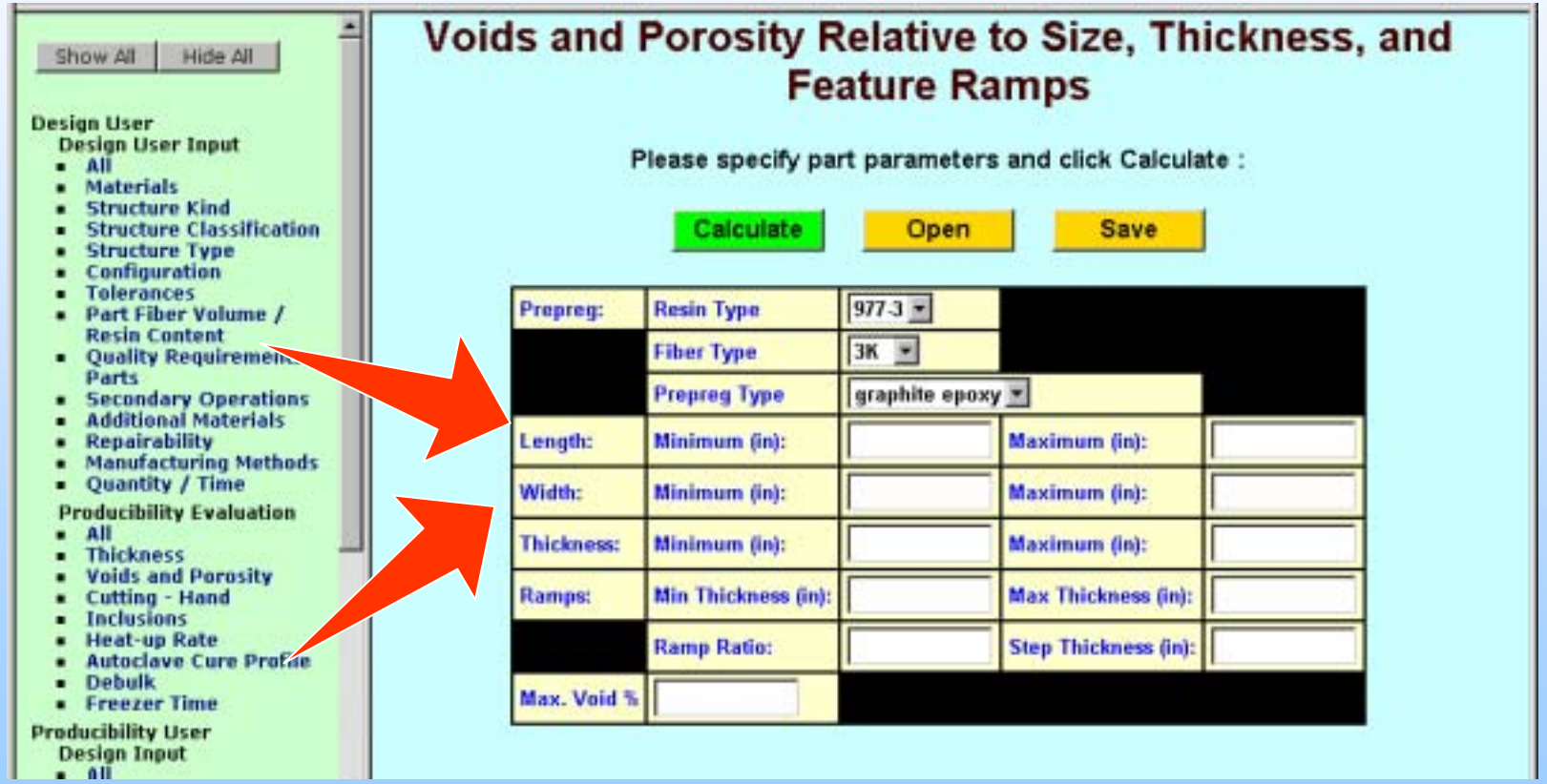
Multiple Output Options and Information

Specifications



Identification of Potential Problems

Producibility – Quality: Voids



Producibility – Quality: Voids

Voids and Porosity :

Prepreg Material

Part Length

Fabricate Producibility Part PP1 (view).

Standard for Length

Part Width

Fabricate Producibility Part PP1 (view).

Standard for W

Part Thickness

Fabricate Produ

Fabricate Produ

Fabricate Produ

Part Feature Ra

Fabricate Produ

Fabricate Produ

Part Thickness

Fabricate Producibility Part PP1T1 (view) and Thin test panel [0.0] inches thick.

Fabricate Producibility Part PP1T2 (view).

Fabricate Producibility Part PP1T3 (view) and thickness scale-up part [0.0] thick.

Part Feature Ramps

Fabricate Producibility panel PP2T1-2R1 (view).

Fabricate Producibility panel PP2T[0.0 or 1]-[0.0 or 2]R[0.0 or 1) (view).

Part Quantity - Voids

NDE Standards (Effect of Defect)

Fabricate NDE standard part PP_NDE2 (view) with [0.0 %] voids.

Fabricate NDE standard part PP_NDE2 (view) with 2X[0.0 %] voids.

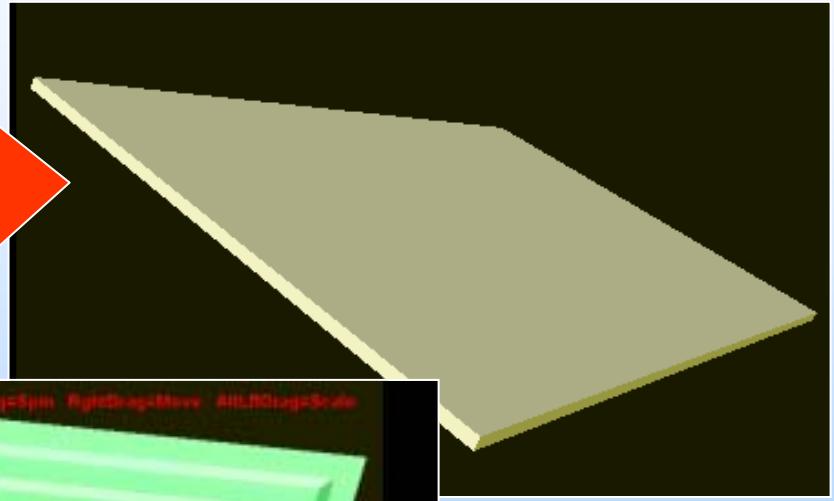
Fabricate NDE standard part PP_NDE2 (view) with 3X[0.0 %] voids.

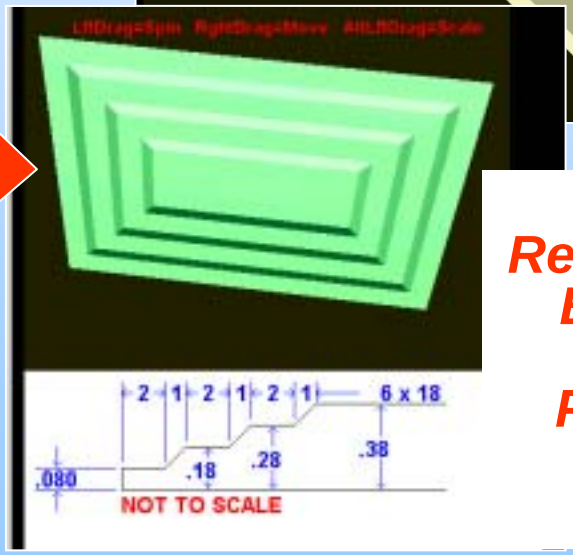
Mechanical Property Panels (Effect of Defect)

Fabricate Compression test Panel(s) CTP1 (view) with [0.0 %] voids.

Fabricate Compression test Panel(s) CTP1 (view) with 2X[0.0 %] voids.

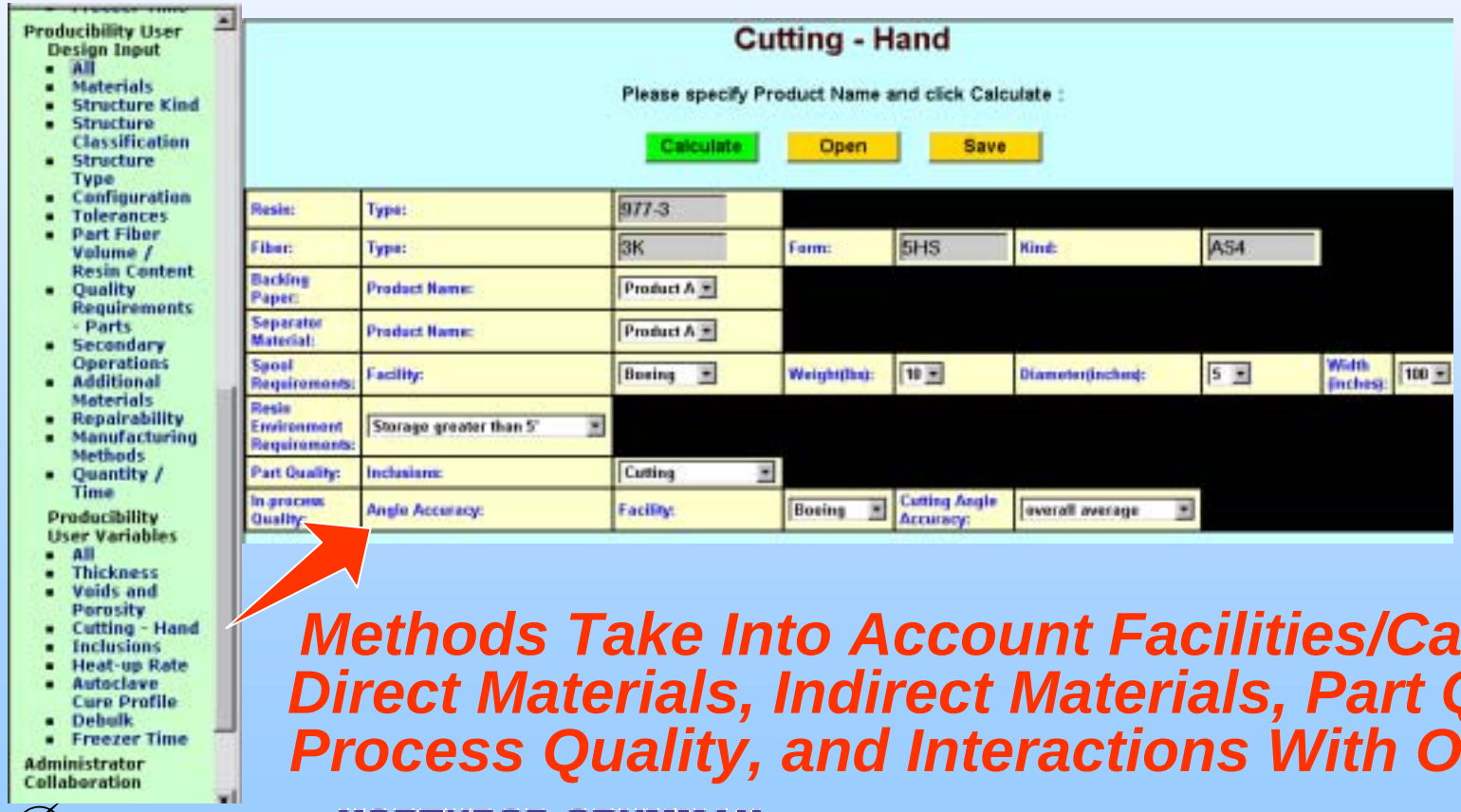
Fabricate Compression test Panel(s) CTP1 (view) with 3X[0.0 %] voids.





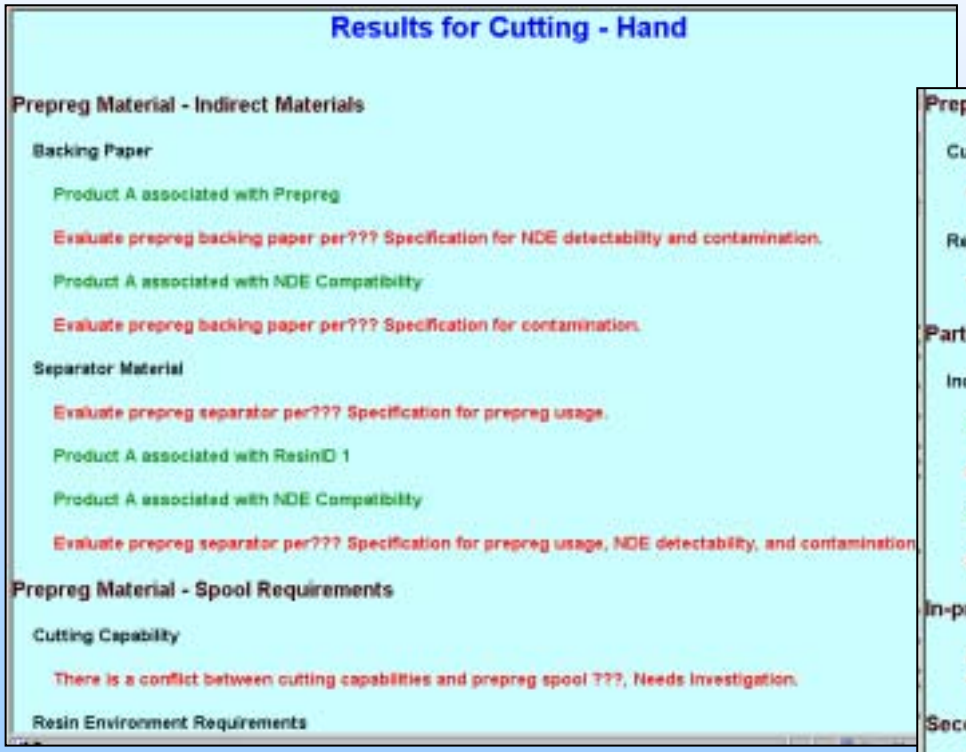
Output Recommendations Based on User Inputs, Std Produce Tests, and Lessons Learned

Producibility – Method: Cutting



Methods Take Into Account Facilities/Capabilities, Direct Materials, Indirect Materials, Part Quality, In-Process Quality, and Interactions With Other Items

Producibility – Method: Cutting



Results for Cutting - Hand

Prepreg Material - Indirect Materials

Backing Paper

Product A associated with Prepreg

Evaluate prepreg backing paper per??? Specification for NDE detectability and contamination.

Product A associated with NDE Compatibility

Evaluate prepreg backing paper per??? Specification for contamination.

Separator Material

Evaluate prepreg separator per??? Specification for prepreg usage.

Product A associated with ResinID 1

Product A associated with NDE Compatibility

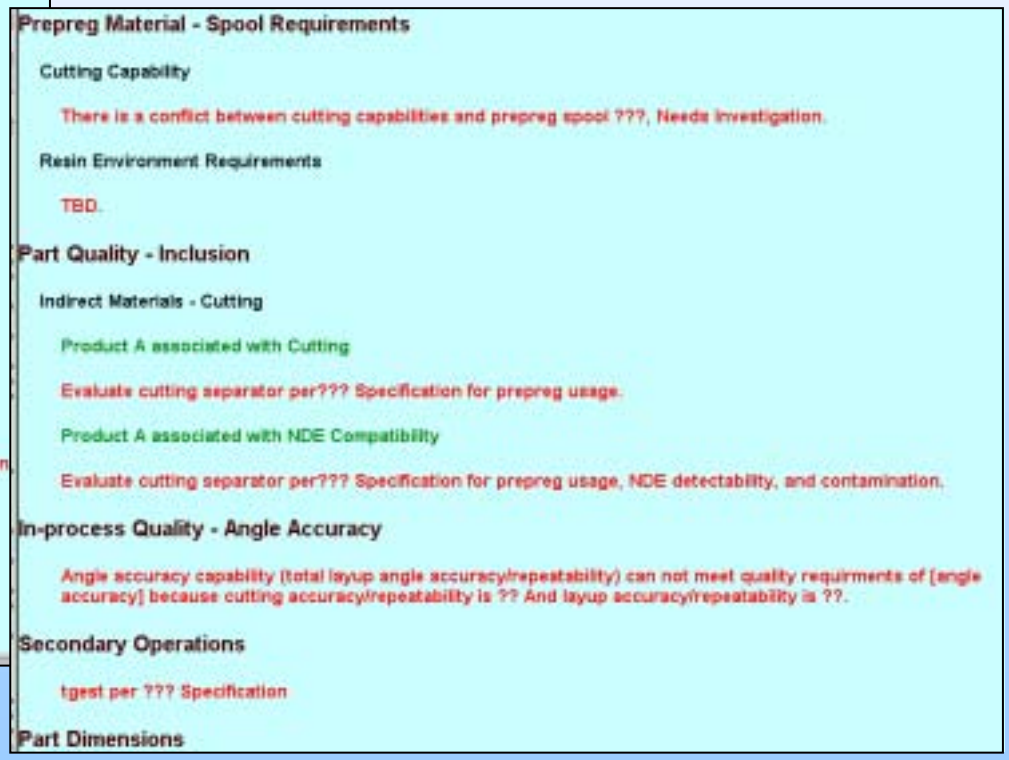
Evaluate prepreg separator per??? Specification for prepreg usage, NDE detectability, and contamination.

Prepreg Material - Spool Requirements

Cutting Capability

There is a conflict between cutting capabilities and prepreg spool ???, Needs Investigation.

Resin Environment Requirements



Prepreg Material - Spool Requirements

Cutting Capability

There is a conflict between cutting capabilities and prepreg spool ???, Needs Investigation.

Resin Environment Requirements

TBD.

Part Quality - Inclusion

Indirect Materials - Cutting

Product A associated with Cutting

Evaluate cutting separator per??? Specification for prepreg usage.

Product A associated with NDE Compatibility

Evaluate cutting separator per??? Specification for prepreg usage, NDE detectability, and contamination.

In-process Quality - Angle Accuracy

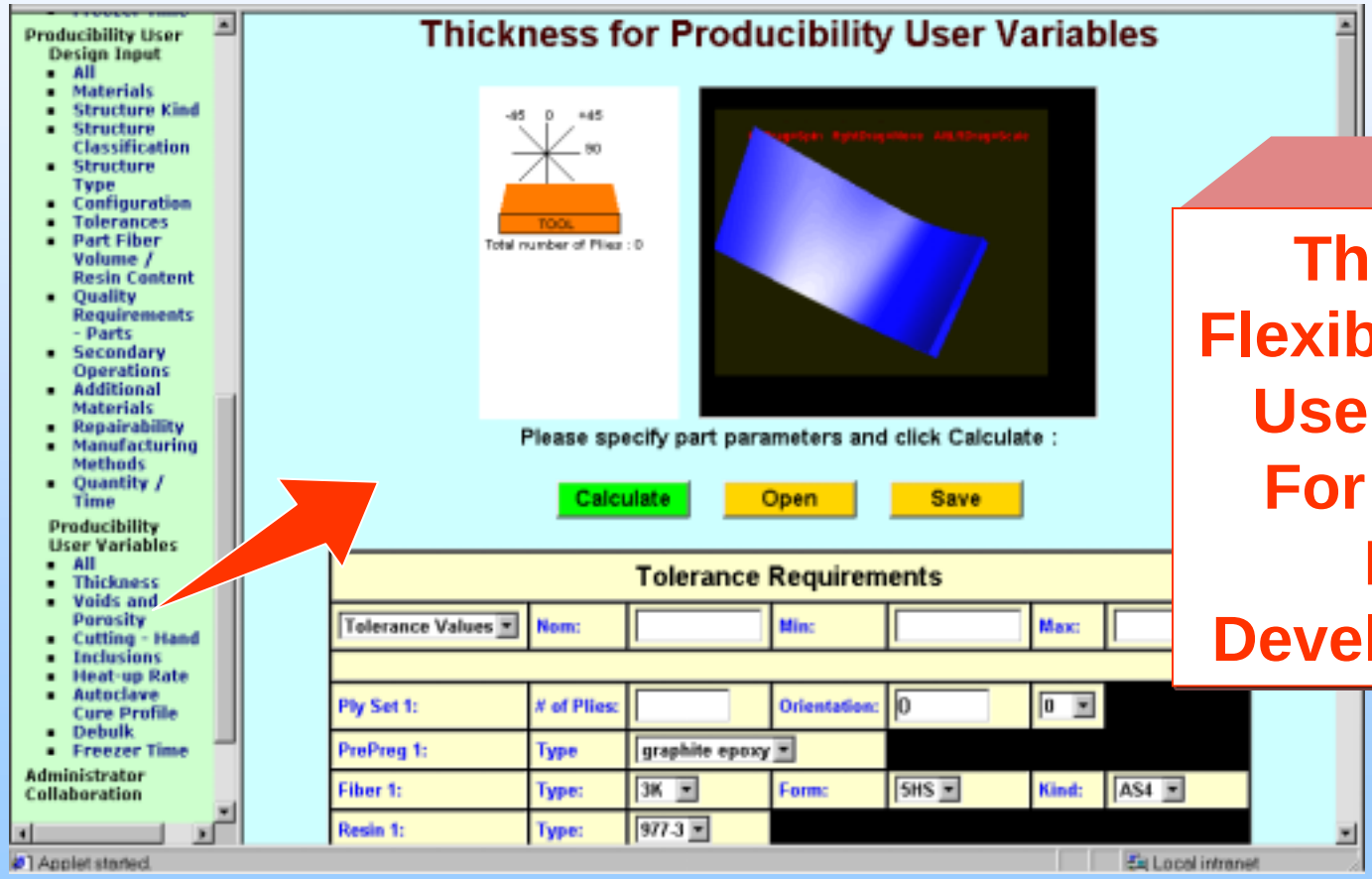
Angle accuracy capability (total layup angle accuracy/repeatability) can not meet quality requirments of [angle accuracy] because cutting accuracy/repeatability is ?? And layup accuracy/repeatability is ??.

Secondary Operations

tgest per ??? Specification

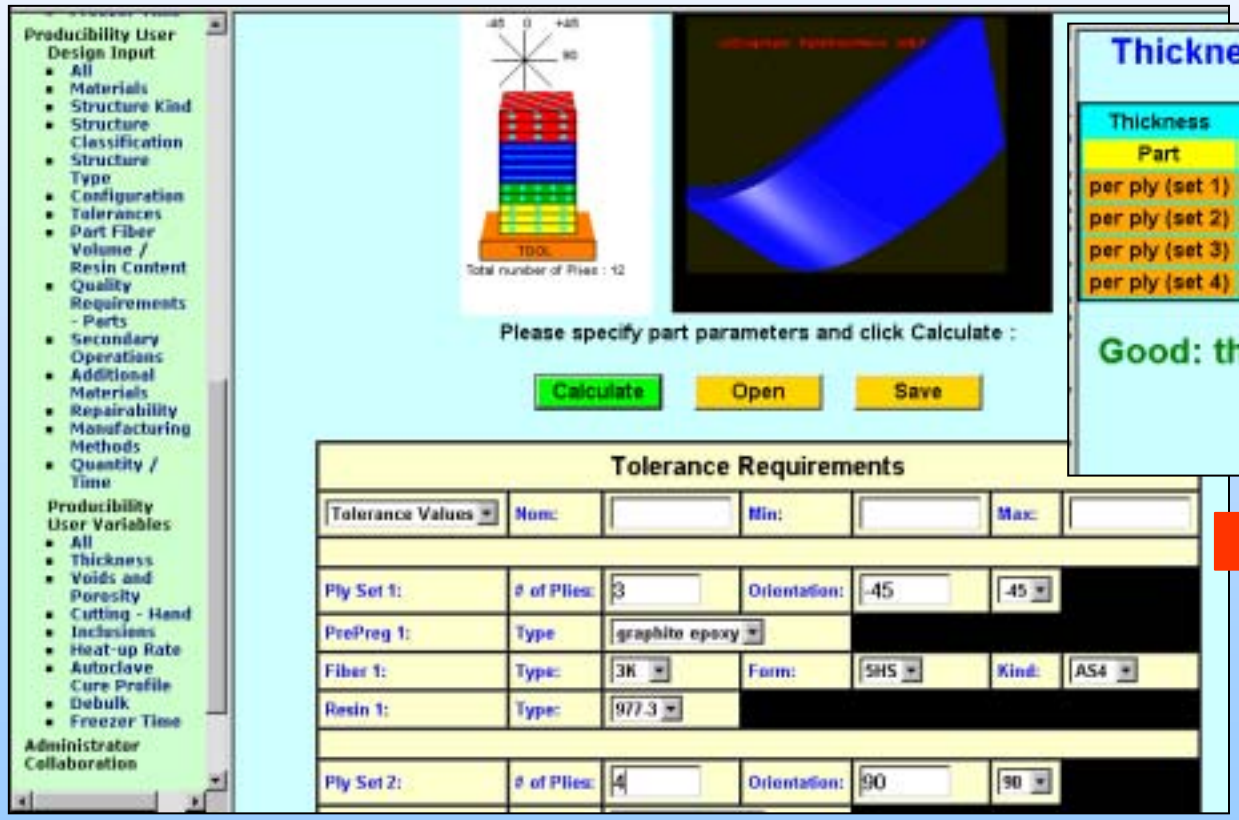
Part Dimensions

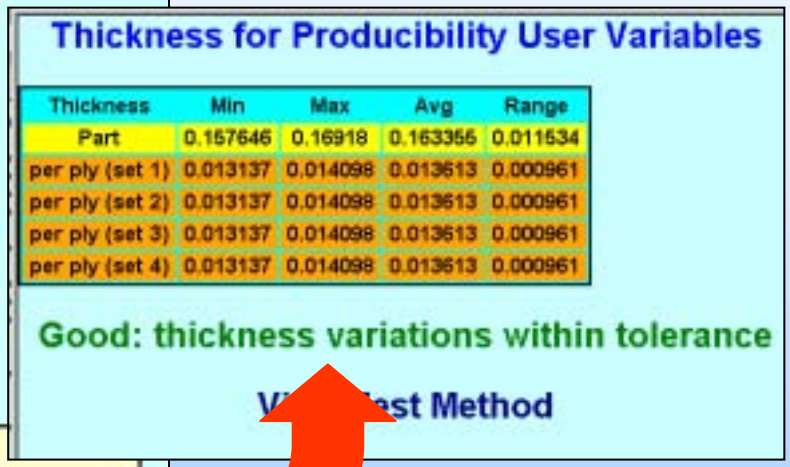
Producibility User Producibility – Quality: Thickness



The Module Is Flexible So Different Users Can Use It For Their Needs Later In a Development Cycle

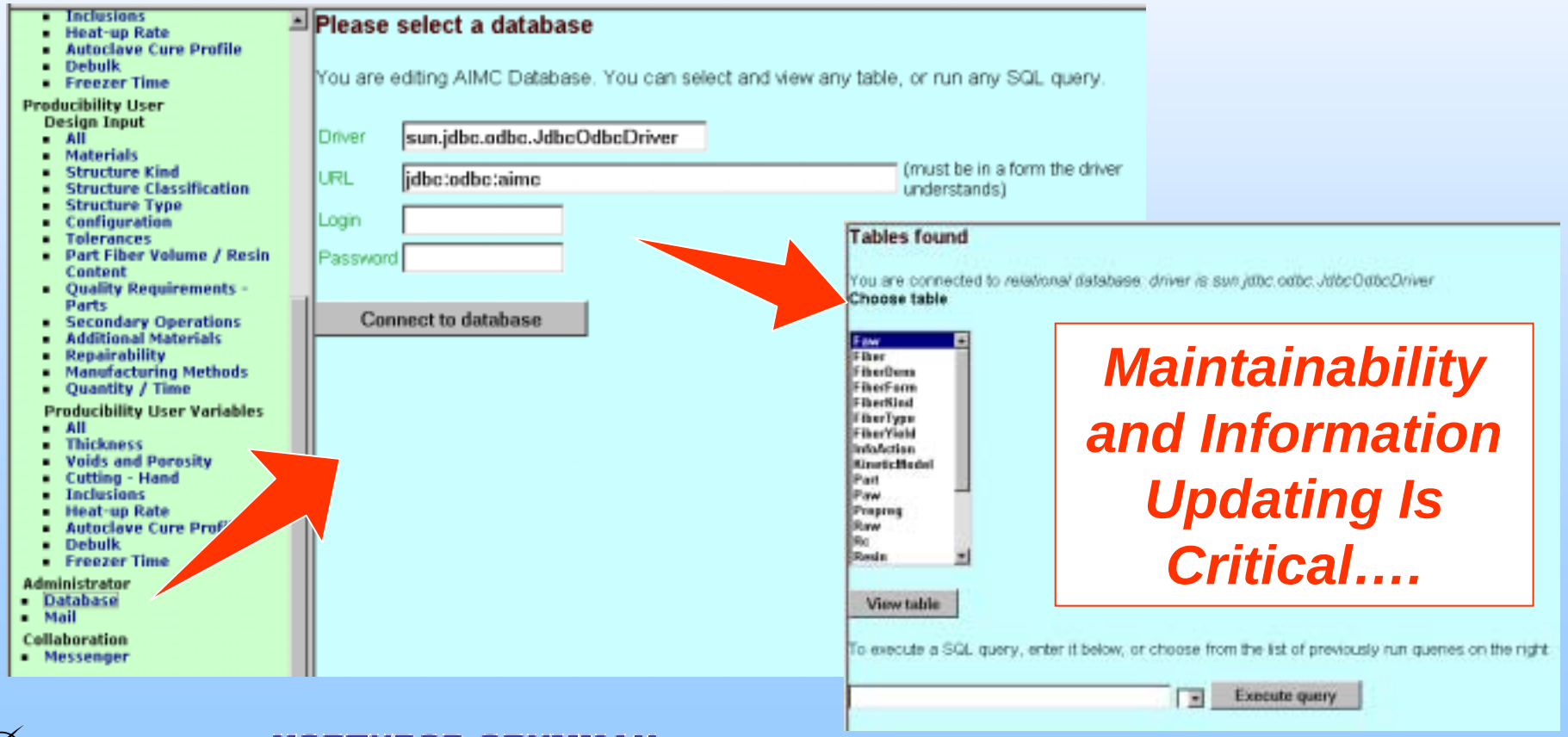
Producibility User Producibility – Quality: Thickness



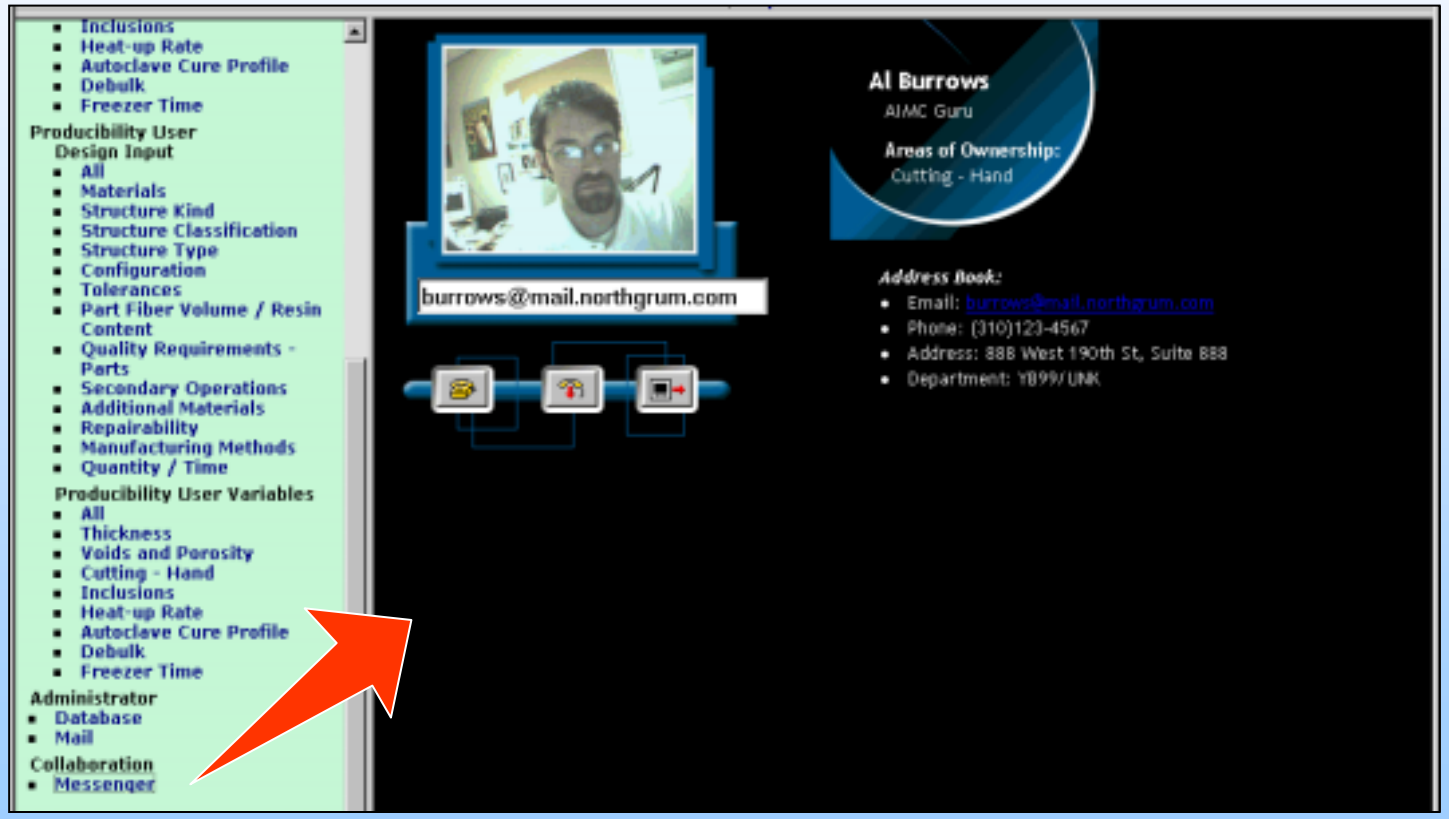


Output According To Needs

Administrator User Data Base Management



Collaboration User Messenger



Summary

- ***Basic Effort Accomplishments:***
  - Design User Interface for Producibility
  - Producibility Quality Areas of Thickness and Voids
  - Producibility Operation/Processing Area of Cutting and Indirect Materials
  - Recommendations Based on Inputs and Lessons Learned
  - Integration of Producibility Module Multiple Component Pieces
  - Integration of Producibility Module with other Modules

Future Plans

–Populate Module For Core Flat Panel Fabrication Producibility Analysis

–Populate Module For Panel With Ramp Feature Fabrication Producibility Analysis

–Populate Module For Flat Panel With Co-cured Hat Stiffener Fabrication Producibility Analysis

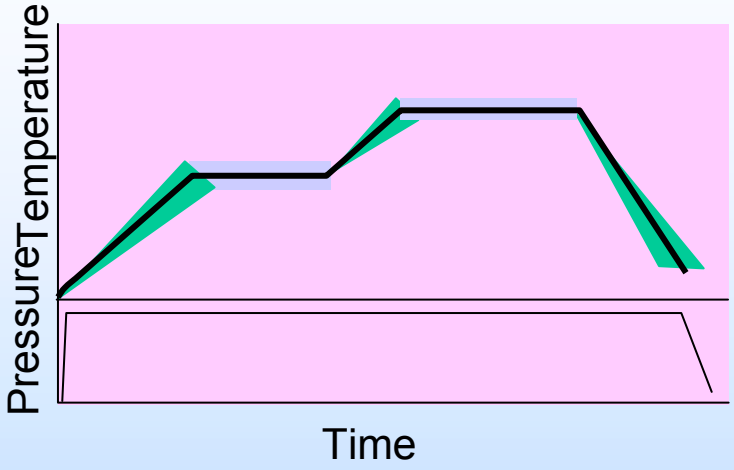
–Populate Module To Perform Producibility Analysis With Combination Of Co-Cured Hat Stiffened Panels And Ramps To Support The Compelling Demonstration

A Feature Based Producibility Assessment Through Parameterized Process Modeling

- Motivation
  - –Augment current heuristic approach for cure cycle design with a physics based prediction methodology
  - –Make a high-end analysis tool (AIM-C Processing Module) available for design through RDCS
  - –Demonstrate integration between the web based front-end of Producibility and RDCS
- Integration approach
  - –Parameterize AIM-C Processing Module input/output
  - –AIM-C Processing Module embedded in a Math model
  - –Web based GUI for a design process (genetic optimization)
  - –Producibility module creates RDCS batch file
  - –Pilot version of invoking RDCS on the designer's desktop
  - –Design exploration to find cure cycle that meets heat-up requirements
- Accomplishments
  - –Designed feasible curing cycle that met heat-up requirements
  - –Identified fabrication processes that are likely to result in defective parts

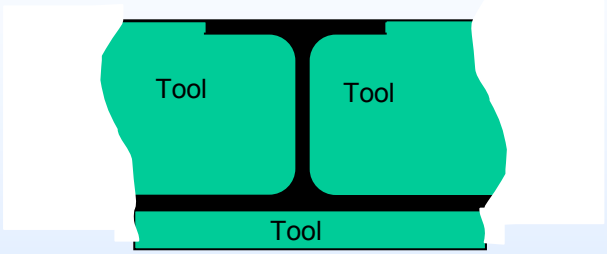
Use Scenario and Problem Statement

Composite System Cure Requirements

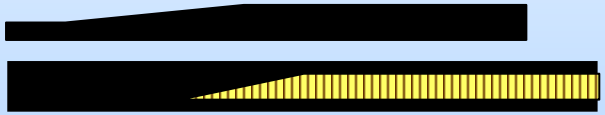


- Resin chemistry requirements
- In-cure and residual stresses
- Minimum and maximum rates
- Minimum and maximum hold times
- Intermediate temperature holds

Design and Tooling Requirements



Thermally massive tooling, inserts
Co-cure Tail, Ti Wing Root

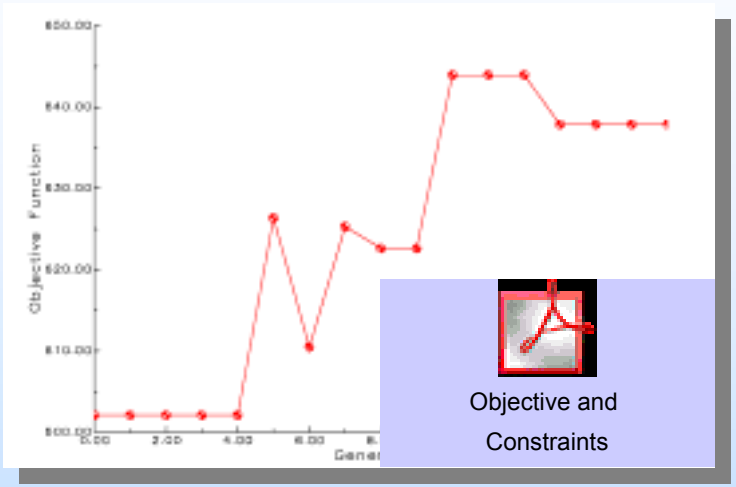


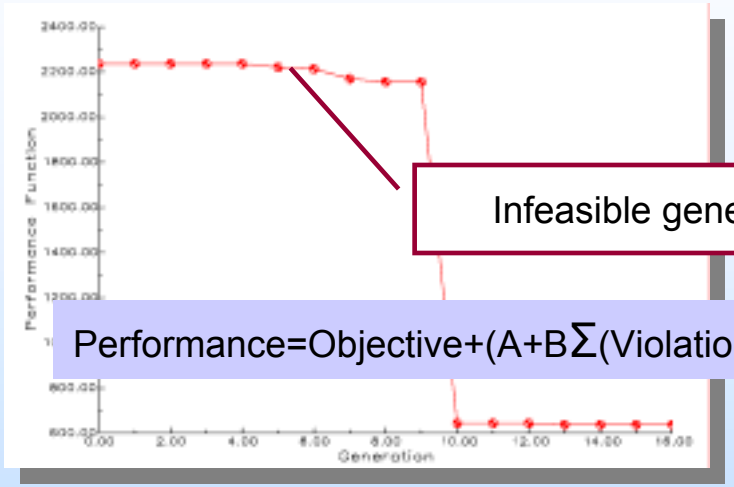
Thick and Thin Sections
Keel beams, Attachment points

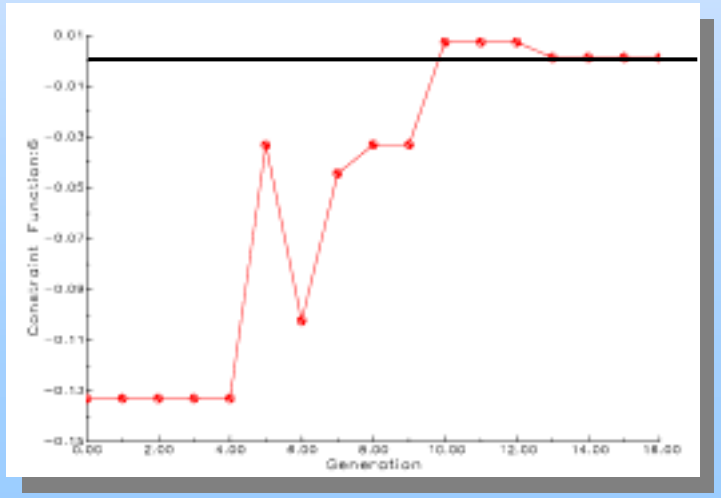
Combinations of Above

Evaluate Design Driven Requirements Relative to Material and Processing Requirements for Heat-up Rate and Exotherm Producibility Issues

Representative Results: Thin part, thick aluminum tool







Important constraints

4 - Minimum part heat-up rate at ramp 2

5 - Maximum time at final cure temperature

6 - Minimum time at final cure temperature

7 - Maximum acceptable heat-up gradient

Resource needs: ~ 550 evaluations

3 hrs wall clock time (100 workstations)

Conclusions

- Demonstrated Integrated Producibility-Processing-RDCS Design Tool
- Tool was used to search for feasible heat-up cure cycles
- Feasible designs were not found in all cases
  - Insight into the process
  - Options: change tooling material or relax constraints
  - This is precisely what the AIM-C facilities are intended for:

Identify and solve design/producibility problems early to avoid cost and schedule overruns

AIM-C Reduces Time and Cost of Insertion by Understanding the Actual Manufacturing and Structural Analysis of Real Applications